THE POTENTIAL GAIN TO BE ACHIEVED BY GENERALIZATION OF SEAT BELTS AND AIRBAGS IN TRUCKS

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ABSTRACT

In recent years, throughout Europe, truck manufacturers have developed and installed occupant restraint systems similar to those that have been available in passenger vehicles for a long time. The development of truck seatbelts and steering-wheel mounted airbags is based on occupant safety research, and the need to meet European safety regulations which will come into effect in the near future. This paper aims to evaluate the potential efficiency of a seat belt coupled to an airbag. The study is based on the CEESAR truck accidents database. The sample includes 403 accidents which involved 479 unbelted occupants (all injury level). The injury causation mechanism according to the type and the severity of the crash enable us an effectiveness evaluation based on a supposed 100 % seat belt (and air bag) use rate. The use of seat belts with 3 anchoring points mounted on the seat of trucks (with an airbag) would be effective for 37 % of fatalities, 36 % of seriously injured and 22 % of slightly injured occupants.

INTRODUCTION

It is well-known world wide that the use of safety belts, eventually coupled with an airbag, is one of the most effective safety measures in the fight to save thousands of lives each year.

In France, although about 90 % of front seat car occupants wear their seat belt in rural areas (about 80 % in urban areas), in depth accident statistics indicate that more than 40 % of fatally injured occupants had not buckled up. French car manufacturers estimate that approximately 1.000 lives could be saved in passenger cars each year (of a total of 5100 fatalities) if all drivers and passengers wore seat belts.

Belt use by passenger car occupants has been a subject of discussion for quite some time and is now becoming more and more important for truck occupants. This paper discusses the potential benefit of seat belt and airbag use for truck occupants, especially drivers.

After a brief recall of the results published in previous studies and of the legislative issues, we propose to estimate the expected number of occupants who could be saved or less severely injured had they worn a seat belt. We used in-depth truck accident investigations and based our analysis upon a case by case review. For each case selected, we identified the general characteristics of the accident (especially the type of impact) and the injury causes and decided whether a seat belt could have influenced the injury outcome. By comparing French national statistics and our in-depth database, we are able to quantify the total number of occupants who could have benefited from a seat belt.

Previous Research:

The results of 11 recent studies are given below (Table 1).

Table 1
Truck Seat Belt Efficiency

Author	Sample Size	Seat belt efficiency min/maxi (%)	Study type
Grattan 1975	51	30/50	Unknown.
Hogstrom 1980	124	65/75	OTS
Stocker 1986	400	50	Unknown.
Langwieder 1988	770	18/78	Unknown.
Svenson 1994	20	50/70	OTS
Higges 1994	140	57	POLICE
Bar 1995	156	12	OTS/POLICE
Botto 1996	214	51	OTS
Groer 2000	56	55/80	Unknown.
Avedal 2000	124	60	OTS
Breitling 2000	195	22	Unknown.

The authors are unanimous in their conclusion that seat belt wearing decreases the level of occupant injury, although the gains are not the same for all the studies. It should be noted that the studies are based on different populations. The first 10 studies estimate a decrease in the level of occupant injury for all personal injury accidents. The last one concerns only fatal accidents. The databases used are either from "On The Scene" truck crash investigations or are based on police reports (POLICE). The summary of these results shows truck seat belt efficiency to be:

between 50 % and 60 % for all injuries

22 % for fatal injuries

To date, French legislation on truck equipment has followed European Union (EU) directives. The first directive, in July 1992 made seat belt anchors compulsory for all new trucks. Further legislation in October 1999 made fitting seat belts to trucks obligatory. This directive is valid for all commercial and heavy vehicles (N1, N2 and N3).

The EU has also proposed an amendment whereby all truck and coach passengers must wear seat belts (December 11 2000).

French legislation on the use of truck seat belts has not yet come into effect.

In Europe, Belgium and Germany have already made seat belt wearing obligatory. In Germany, seat belts have been compulsory since 1992. Nevertheless, it is claimed that less than 5% of drivers actually wear their seat belt (Berg, 2000).

In France, the exact belt-wearing rate in trucks is unknown. 1998 accident results from the SETRA (Service d'Etudes Techniques des Routes et Autoroutes), give a wearing rate of 12 % amongst drivers involved in accident (declared by drivers).

More realistically on the other hand, a road inquiry carried out by ASFA (Association des Sociétés Françaises d'Autoroutes), on 2874 trucks, shows a wearing rate of 1.5 % (observed by the researchers).

Although the seat belt wearing rate in France is still very low, some companies have adopted, through in-house safety programs, a compulsory seat belt policy for their drivers. This is notably the case for the petrol transport industry.

STAKES

If we assume, through effective legislation, a 100 % seat belt use rate, it is interesting to know what gain in occupant safety could be expected. The aim is to provide occupants with a polyvalent restraint system that is effective against all possible injury causation mechanisms.

Although a "zero injury" goal may seem utopian, an overall severity decrease certainly seems realistic.

Table 2 shows that 60 % (3929/6512) of all accidents involving at least one truck are not concerned by a seat belt effect (lateral or rear end crashes).

In France in 1998, 68 truck occupants were fatally injured and 943 truck occupants were either seriously or slightly injured in road accidents.

Table 2
Distribution Of Casualties In Trucks With A Breakdown By Truck Accident Types In France (Source: National Statistics ONISR, 1998)

	Accidents	**Fatalities**	**Seriously injured**	**Slightly injured**	**Not injured**	**Total Involved**
Frontal impact						
Car to Truck	1911	10	38	208	1783	2039
Truck to Truck	155	17	45	124	79	265
Truck / obstacles	407	38	138	271	29	476
Truck in Tip-over	110	3	19	100	10	132
Accidents concerned by belt	**2583**	**68**	**240**	**703**	**1901**	**2912**
Others	3929	40	122	534	3869	4565
Total	**6512**	**108**	**362**	**1237**	**5770**	**7477**

SEAT BELT EFFICIENCY

A look at current and future truck restraint systems is useful to assess the type of accidents in which they would be effective.

There are 3 restraint system types:

- Seat belt with 2 anchoring points mounted on the seat (found in old trucks)
- Seat belt with 3 anchoring points mounted on the seat (already available in newer trucks)
- Seat belts with 3 anchoring points mounted on the seat, pretensioner and air bag (as standard or optional equipment).

The first two seat belts offer the same level of protection in frontal impact, by limiting longitudinal body displacement. Previous studies show that the HIC (Head Injury Criteria) for a belted dummy is lower than for an unbelted dummy (Alexander, 2000), and can fall below the critical threshold value for a 32 km/h crash test (Hori, 1987). In extreme cases, seat belt slack allows head to steering wheel contact, resulting in injury. If the seat belt is combined with a pretensioner (effective from 12 to 15 ms after the start of the deceleration phase), the body is correctly coupled to the seat (Gulde, 2000). If, furthermore, the restraint system includes an air bag, direct head to steering wheel impact is prevented (Zeller, 2000; Breitling, 2000)

Other crash types like jack-knifing, tip-over and rollover result in complex body movements. Other studies carried out on this accident types show that seat belt efficiency depends on crash speed, roll direction and rotational axis (A.Zeller, 2000). In a clockwise rollover crash, the thoracic part of the seat belts, with 2 or 3 seat-mounted anchoring points, does not keep the driver (front left seat) in place. Only the abdominal belt is effective, maintaining the pelvis in contact with the seat and thus preventing ejection. In a counter-clockwise rollover, the

geometry of the seat belt with three seat-mounted anchoring points limits chest and head displacement. It also limits chest torsion.
Seat belt pretensioners will be most effective if triggered by transversal acceleration and rollover sensitive captors, rather than the traditional longitudinal acceleration system used today.

SAMPLE

The sample is selected among the accident database (540 accidents) constituted by CEESAR according to an in depth investigation methodology.
The accident selection criteria used for this study are based on the main crash types that may benefit from the use of a restraint system:

- Frontal crash (against another vehicle)
- Frontal crash (truck as single vehicle)
- Rollover and tip-over

The main crash is considered here as the one that causes the most serious injuries.

The sample includes 403 truck crashes, which meet the crash criteria mentioned above, including all injury levels, coded with the MAIS or Maximum Abbreviated Injury Scale (the highest AIS of all body segments from 0 unhurt to 6 fatal). In order to have same categories such as others studies, we grouped MAIS in 4 classes (Table 3) :

- Unhurt occupants are MAIS 0
- Slightly injured occupants are MAIS 1 or 2
- Severely injured occupants are MAIS 3 ,4 or 5
- Fatally injured occupants are MAIS 6

In France, accidents are considered as fatal if death occurs within 6 days. For secondary safety research purposes, an accident is considered as fatal if the occupant dies as a direct result of the injuries sustained whatever the delay between the crash and death.

Table 3
Distribution of Casualties in Trucks with a Breakdown by Truck Accident Types in France (Source: CEESAR-Renault VI. Sample, 2001)

	Accidents	Fatalities	Seriously injured	Slightly injured	Unhurt	Total Involved
Car to Truck	190	0	0	8	199	207
Truck to Truck	49	9	12	25	46	92
Truck with obstacles	43	5	5	25	12	47
Truck in Rollover	121	10	12	72	39	133
Total	403	24	29	130	296	479

None of the 479 occupants involved in the above accidents were wearing a seat belt, even though certain vehicles were equipped.

METHODOLOGY

Accident analysis was carried out in several steps. In order to know if there is a correlation between the crash violence and the injury level, we evaluated crash violence factors such as EES, crash speed and delta V (all defined later). Then we linked these factors to the injuries for each occupant and, with the crash, we were able to define three injury causation mechanisms.
The case by case analysis is realised according to the crash violence, the injury causation mechanism and the MAIS of each truck occupant in order to evaluate his potential MAIS if he wears the belt and if the vehicle is equipped with an airbag.

Crash Violence Evaluation.

For all accidents, cinematic reconstruction is carried out from the final rest position.
Post collision and pre collision calculations use information picked up “on the scene” (skid marks, sliding marks, scraping, road state, vehicle state and equipment) and occupant information (action, physical state…)
Crash calculation is based on energy conservation equations (motion quantity and kinetic energy).
Crash speeds are calculated using 3 equations:
Conservation of momentum along the x and y axes

$$M_1V_{E1}cos(\alpha_1)+ M_2V_{E2}cos(\beta_2)= M_1V_{S1}cos(\alpha_{s1})+ M_2V_{S2}cos(\beta_{s2}) \quad (1)$$

$$M_1V_{E1}sin(\alpha_1)+ M_2V_{E2}sin(\beta_2)= M_1V_{S1}sin(\alpha_{s1})+ M_2V_{S2}sin(\beta_{s2}) \quad (2)$$

Kinetic energy conservation:

$$1/2M_1\ V_{E1}^2+1/2M_2\ V_{E2}^2= 1/2M_1EES_1^2+1/2M_2EES_2^2+1/2M_1\ V_{S1}^2+1/2M_2V_{S2}^{\ 2} \quad (3)$$

M_1 *and* M_2 are the laden weight of the vehicles (kerb weight, load and occupants) in kg
α_1 *and* β_2 are the crash speed vector angles
α_{s1} *and* β_{s2} are the post-crash speed vector angles
EES_1 *and* EES_2 are the Equivalent Energy Speeds in m/s
V_{E1} *and* V_{E2} are the crash speeds in m/s
V_{S1} *and* V_{S2} are the post-crash speeds in m/s

Truck EES are estimated by referring to the truck manufacturers’ experimental crash tests (photo library), crash test cinematic reconstruction and European studies such as the EACS database (European Accident Causation Survey), and take into account the following information:

Cab crush,
Cab rearward movement,
TDC (Truck Deformation Classification): crash direction, height, overlap,

VDI (Vehicle Deformation Index): intrusion position in the cab,
Adverse vehicle under run (bumper height and under run measurement),
Gross train weight,
Adverse vehicle

For car EES, several French studies were used; in depth accident investigation carried out by CEESAR, (Centre Européen d'Etudes de Sécurité et d'Analyse des Risques), secondary safety studies carried out by LAB (Laboratoire d'Accidentologie et de Biomécanique) and their crash test photo library.

V_{S1} and V_{S2} are calculated from the distance between the point of impact and the rest position « d_i » for each vehicle, measured "on the scene", and the grip coefficient of the road and the inferred average vehicle deceleration « γ ».

$$V_{Si}^{\ 2} = 2d_i\gamma_i \ (4)$$

V_{E1} is calculated or estimated, according to the crash type. In some cases, the number of unknown values for equations (1), (2) and (3) does not allow crash speed calculation (unknown EES, immobilisation distance unknown…). Nevertheless, we can eliminate unknown data by estimating its most probable value.

- Example 1: Standing start. The speed is estimated by applying an acceleration over the distance covered.
- Example 2: Truck rear end crash. The speed is estimated from the tachometer disc if the vehicle does not brake before the crash.
- Example 3: Loss of control of an oncoming car. Car speed is estimated by applying the average crash speed from the in depth investigations carried out since 1990 by CEESAR (there is a difference between at fault and non at fault drivers).

In a crash between 2 vehicles, speeds are estimated with equations (1), (2), (3) and (4). When a single truck is involved alone, only equations (3) and (4) are used.
For tip-over and rollover, V_E is estimated from the distance covered after crash (first contact of the trailer on the ground) and the tachometer speed (F.Bar, CEESAR 1996).

$$V_E = (25+d_r)/1.13 \ (5)$$

d_r is the distance covered after tip-over, in m (skid marks or scraping marks of the trailer on the ground).
V_E, is the speed at the beginning of the tip-over, in km/h.
Crash violence is characterised:

- <u>For tip-over:</u>
  by V_E, the crash starts when the trailer touches the ground and finishes at the rest position.
- <u>For other accident types:</u>
  by the delta V, which is the same as the EES when the position of rest is at the point of impact.

Injury Causation Mechanisms

Each occupant was reviewed in relation to the accident type. First, the injured body segments were coded with the AIS scale to give the type of injuries and their severity. These injuries were then studied in relation to the accident, on a case by case basis, in order to determine injury causation mechanisms. These injury causation mechanisms are the result of a combination of several factors:

- A cause:
  Cab frame deformation
  Passenger cell aggressiveness
- A crash violence criteria:
  Crash type
  Overlap
  Crash height
  Cab frame deformation extent
- And are linked to the occupant by:
  His place in the cab
  His age
  Seat belt use
  Injured body segment

Three injury causation mechanisms are noted:
Intrusion which is characterised by cab frame crush into the passenger cell or by the introduction of an external object.
Cab crush is either along the x-axis (longitudinal axis of the vehicle), or the z-axis (vertical axis of the vehicle).
Projection: the occupant is projected within the passenger cell during the crash. In frontal crashes, the movement is in the forward direction. In the case of a tip-over, the body falls into the cab and may impact aggressive areas. Contact areas found during the study of the cab and the resulting injuries are compared to determine occupant movement.
Ejection: partial or total ejection.

ANALYSIS

Each accident is analysed in detail.
We have examined:

- *The crash*, characterised by: obstacle type, deformation, overlap, crash direction.
- *The crash violence*, with an EES, a crash speed V_E or a delta V,
- *The injury causation mechanisms*

The Crash

Each accident has a different injury causation mechanism according to the type of crash and the obstacle (Table 4):

Table 4
Injury Causation Mechanisms For Each Accident Type

Injury causation mechanism / Crash type	Unhurt	Intrusion	Projection	Ejection	Other	Total
Truck to Car	199	1	5	0	2	207
Truck to Truck	46	25	19	1	1	92
Truck to obstacle	12	10	17	5	3	47
Tip-over	39	9	71	13	1	133
Total	296	45	112	19	7	479

Truck occupants involved in 62 % of accidents (296/479) did not suffer any injury. In the case of injured occupants, the most frequent injury cause is projection 61% (112/183), especially in tip-over. Intrusion is most common (25/45) in truck to truck accidents. On the other hand, accidents between trucks in frontal crashes and another lighter vehicle rarely injure the truck occupant.

MAIS distribution in relation to injury cause shows that ejection and intrusion cause more severe injuries than projection within the passenger cell. (Table 5).

Table 5
Severity Distribution By Injury Causation Mechanism

MAIS	1	2	3	4	5	6	Total
Intrusion	5	11	13	2	0	14	45
Projection	74	29	5	3	0	2	112
Ejection	4	1	4	0	2	8	19
Other	2	4	0	0	0	1	7
Total	85	45	22	5	2	24	183

Crash Violence

In truck to car accidents, 83 % (151/182 known) of truck EES are below 10 km/h. In truck to truck accidents, 84 % (78/93 known) of EES values are below 30 km/h. In truck against obstacle accidents, 82 % (23/29 known) are lower than 40 km/h, (Figure 1):

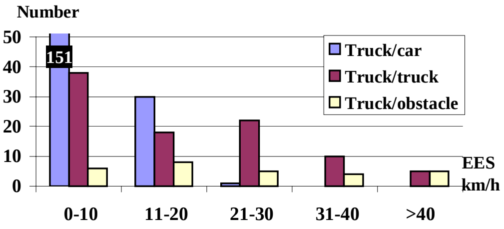

Figure 1.

EES Distribution According To Crash Type

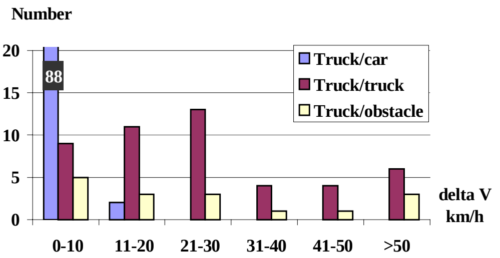

Figure 2.

Delta V Distribution According To Crash Type.

In general, accidents involving a truck are not very severe, as regards the truck.
In truck to car accidents, the delta V is below 15 km/h
In truck to truck accidents, 26 % of trucks involved in frontal crash have a delta V below 10 km/h. 72 % have a delta V lower than 30 km/h.
The evaluation of seat belt effectiveness is carried out according to accident type and occupant injury causation mechanism. Crash violence is the determining factor when 2 causation mechanisms are involved simultaneously: for example, high delta V and low intrusion may favour projection as the main injury causation mechanism.

We then tried to answer 2 questions:

- Would a belt with 3 anchoring points mounted on the seat, with a pretensioner and an air bag be effective?
  The belt with 2 anchoring points on the seat is not analysed because it is only found in old trucks.
- What would the new injury level be, (coded with MAIS) for the belted occupant?

Intrusion:
Seat belt gain can be evaluated on the basis of the intrusion measurement and its position in the passenger cell:

- *In a front to rear impact*, between 2 trucks for example, the impacted truck cab (frontal crash) may have an important front to rear intrusion. The occupant is trapped at lower limb level. A seat belt would have no effect on lower limb injuries (leg, pelvis), but would, depending on the delta V and high intrusion, reduce or prevent upper bodily injuries (chest, head).

- *In tip-over,* roof crush is characterised by intrusion along the z-axis. In this case, if the intrusion is not directly above the occupant, who is supposedly belted and thus maintained in place, the belt would be effective. In the case of intrusion directly above the occupant, measurements in relation to the belted occupant were taken into account in the study.

Projection is the most common injury causation mechanisms (61 %). It is sometimes coupled with intrusion. Crash violence, estimated according to delta V, intrusion value, intrusion position, when compared with injuries for each body segment, are used to choose between two simultaneous causation mechanisms.
81 % of projected occupants, who were injured, have no severe injuries (MAIS 1 or 2).
A seat belt can be effective:

In frontal crashes, where the intrusion is not directly in line with the occupant, the belt may prevent projection.
All minor head (MAIS 1) and chest (MAIS 1 or 2) injuries occurring through contact with the steering wheel and lower limb injuries MAIS 1 or 2 (knees against dashboard) associated with low delta V accidents are prevented with a belt. An occupant, previously MAIS 1 or 2, maintained in his seat, does not come into contact with the vehicle and may thus be considered unhurt MAIS 0.
In the case of a higher delta V, a belt coupled with an air bag may prevent brain trauma with loss of consciousness that can occur with violent forward projection. These injuries are coded MAIS 2. We can estimate that if an MAIS 2 occupant was belted, he would suffer only MAIS 1 injuries.

In tip-over or rollover accidents, a seat belt with 3 anchoring points mounted on the seat prevents projection within the passenger cell (by abdominal retention) especially in clockwise tip-over. In this case, an unbelted driver pivots with the truck and falls. (Templin, 2000). Injuries are often minor. The body segments that are the most often injured are the head, the upper limbs and the chest. Even if there is roof crush, a belt keeps the driver in his seat.
In counter-clockwise tip-over, the occupant is closer to the ground. Although there is still projection, the greatest risk in this case is partial ejection.

Partial and total ejection are the most dangerous injury causation mechanisms (74 % of ejected occupants, who are injured, sustain serious or fatal injuries). This causation mechanism occurs principally during tip-over or during jack-knifing. 14 % of occupants in these accidents are partially or totally ejected.
Among others, a study carried out by CEESAR, on 161 cars shows that, belted or not, it is preferable to avoid ejection. For belted or unbelted occupants, the proportion of partial ejection is the same (5 occupants belted out of a total of 11). For total ejection, the proportion of belted occupants is nearly zero (1 belted out of a total of 13 ejected occupants). Furthermore, the rate of severe injuries (MAIS 3+) for non-ejected occupants is very low even if roof crush occurs (Driscoll, 2000).
The 3 point seat-mounted belt cannot totally prevent head excursion. It limits lateral movement by coupling the body to the seat, but roll speed and direction and sliding distance after the tip-over are all factors that increase the risk of ejection. This observation was noted in particular by Deblois (1994) who, in 2 car rollover simulations, showed body segment movement and ejection coupled, with delta V and roll speed. The risk of ejection is increased by the distance covered during the lateral slide along the ground, where each height change (kerb, ditch, etc…) is a potential source of body excursion.

For unbelted drivers, victim of partial ejection, with no direct intrusion in line with their seat, who wear a 3 point seat mounted belt, the gain may be estimated at a reduction of MAIS 2 injuries, for example brain trauma with a short loss of consciousness. Only a lateral air bag could limit the risk of head excursion. Other concepts like seat pretensioners could be considered. This system limits belt slack by pulling the seat back and down, while maintaining the comfort of the 3 point seat-mounted belt (Templin, 2000).

Statistical Analysis

The statistical analysis of the potential effectiveness of seat belt use with frontal airbag by all occupants (i.e. reduction in accident severity) was done in two-steps. First we estimated the relation between the violence of impact and the injury outcome in the case of a belted occupant with an airbag and an unbelted occupant. Then, we estimated the potential reduction of the number of fatalities and injured occupants in accidents, if all truck occupants wore a seatbelt.

The first analysis gives an expected reduction in injury risks whereas the second analysis gives an overall reduction in casualties to be expected in France, assuming that all occupants wear a seat belt.

The potential reduction in injury risk is estimated with the help of a logistic regression model linking the injury outcome (the probability of MAIS 3+ injuries) and the violence of the impact (The Equivalent Energy Speed). See equation (6)

$$P(MAIS\ \ 3+) = \frac{1}{1+\exp\left[-\left(\alpha + \beta_{EES} * EES\right)\right]} \qquad (6)$$

Additional variables such as the truck velocity before the impact or the age of the occupant were tested but were not statistically significant. The potential injury causation mechanism (intrusion, projection, and ejection) was not available for non-injured occupants and was thus not integrated into the model.
Accident types were studied separately. However, as there were few truck occupants injured in car to truck accidents in our selected sample, and as there is no available EES for trucks involved in tip-over, it was not possible to carry out a statistical analysis for these accidents.
Figures 3 and 4 show the estimation of truck occupant injury risk (MAIS 3+) in an accident involving at least one truck in a frontal impact.

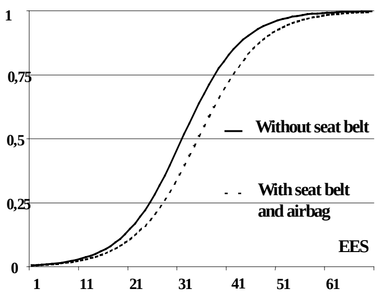

Figure 3.

Risk For Truck Occupant Injury (MAIS 3+) In A Truck To Truck (Frontal Impact) Accident With Or Without Seatbelt.

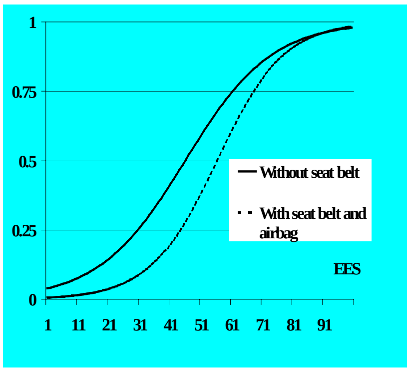

Figure 4.

Risk For Truck Occupant Injury (MAIS 3+) In A Truck (Frontal Impact Other Than Against a Truck) With Or Without Seatbelt.

Logistic regressions were performed with the SAS Statistical package. Parameters are estimated by using the maximum likelihood method for truck to truck accidents, 90 observations were available (28 observations for other truck frontal impacts). The goodness of fit of the four models (presence of seat belt * type of accidents) was very good since all Somer's D were greater than 0.75. The four βs and the intercepts were highly significant (Table 6).

Table 6
Results Of Logistic Regression

	Int.	β	p (for β)	Somer's D
Truck to Truck. With seat belt	-5.2	0.15	0.0002	0.75
Truck to Truck. Without seat belt	-5.1	0.16	0.0001	0.75
Truck to Obstacle. With seatbelt	-5,16	0.09	0.008	0.87
Truck to Obstacle. Without seatbelt	-3.26	0.07	0.006	0.75

Nevertheless, goodness of fit could have been better since the probability of being injured (MAIS 3+) is, in the model for truck to obstacle accidents, not close to zero for EES values below 25 km/h as was expected. This lack of goodness of fit for low values of EES is a consequence of the low number of observations and set of values fairly dispersed along the EES axis.

The models show:
for truck to truck accidents: a slight decrease in the injury risk (MAIS 3+) for EES values between 20 km/h and 50 km/h for occupants wearing a seatbelt compared to unbelted occupants. The decrease in injury risk is almost constant over the EES values (between 10 to 12 points). The risk is very high (more than 90 %) as soon as EES exceeds 50 km/h.
For other truck frontal impacts: the potential benefit of seat belt use is very high, especially for low or moderate EES. For these types of accident, and for a given EES with or without seat belt, injury risk is lower than for truck to truck accidents.
This can be explained mostly by the cause of the injury in these accidents: as intrusion is more frequent in truck to truck impacts (a number of cases of intrusion, high impact over the longitudinal chassis beams in the case of truck rear end crash); projection and partial ejection are more frequent in other frontal impacts (overall impact on the front cab, higher EES but not necessarily in direct relation with MAIS); and intrusion injures more than projection.
Furthermore, the relative uselessness of seat belts in cases of intrusion as well as their relative usefulness in preventing projection can explain the lower potential benefit of seat belts observed for truck to truck accidents.

As there is only a low proportion of very high speed accidents generating high EES, the potential benefit to be expected in the injury risk (probability to be seriously injured with a MAIS equal or greater than 3) is somehow high.

RESULTS AND DISCUSSION

Results

As previously explained, case by case analysis shows that the estimation of the potential gain from seat belt use in trucks depends on the type of accident. Each occupant has an MAIS which reflects his injury level. The analysis allows us to evaluate a new MAIS which depends on seat belt use. As in other studies, the MAIS are grouped in 4 categories (Table 7). The effectiveness is the potential reduction of fatalities and injuries.

Table 7
MAIS Distribution Without And With Seat Belt For Each Accident Type

Type	MAIS	Unhurt	Slightly injured	Severely injured	Fatally injured	Unknown	Total
Truck/ car	Unbelted	199	8	0	0		207
	Belted	**204**	**3**	**0**	**0**		**207**
Truck/ Truck	Unbelted	46	25	12	9		92
	Belted	**60**	**15**	**11**	**6**		**92**
Truck/ obstacle	Unbelted	12	25	5	5		47
	Belted	**30**	**11**	**3**	**3**		**47**
Tip-over	Unbelted	39	72	12	10		133
	Belted	**93**	**33**	**2**	**4**	**1**	**133**

Occupant injury analysis shows that the seat belt would be more effective for slight injuries in all accident types, and for severe injuries and fatal injuries in tip-over accidents.

We wanted to know which injury causation mechanism is more concerned by seat belt use. Therefore we used the previous analysis and looked at what happens to truck occupants according to their injury causation mechanism if they wear a seat belt (Table 8)

Table 8
Expected Gains With Belt For Each Injury Causation Mechanism.

		unhurt	Slightly injured	Severely injured	Fatally injured	Total
Intrusion	Unbelted	0	16	15	14	45
	Belted	**2**	**16**	**16**	**11**	**45**
Projection	Unbelted	0	102	8	2	112
	Belted	**75**	**36**	**0**	**1**	**112**
Ejection	Unbelted	0	5	6	8	19
	Belted	**11**	**6**	**1**	**1**	**19**

Table 8 shows that projection and ejection are the most representative injury causation mechanisms concerned by seat belts.

Effectiveness

The overall estimation of the effectiveness of seat belt use by truck occupants was performed by weighting estimates by accident type according to their weight among the total number of accidents concerned involving at least one truck and according to seat belt use in France in 1998 (Table9).

As the number of casualties in accidents involving a car and a truck is very low in the CEESAR database, it was not possible to estimate a potential reduction of either fatalities or injured occupants for this accident type.

Table 9
Potential Benefit Of Seat Belt Use For Frontal Impact Truck Accidents

	Concerned accidents (CEESAR)	Trucks accidents 1998	All accidents 1998
Fatalities	-51 % [-71%,-31%]	**-37 % [-51%;-23%]**	40/8437
Serious Casualties	-64 % [-81%;-47%],	**-36 % [-46%;-26%]**	130/33977
Slight Casualties	-54 % [-62%;-46%;].	**-22 % [-25%;-19%]**	270/134558

Confidence intervals are estimated for 95 % confidence. Their large magnitude is due to small samples.

As pointed out previously (Table 2), seat belts could be useful for approximately 40 % of all truck accidents. Table 9 shows that we could expect from seat belt an overall reduction of 37 % of fatalities, of 36 % of serious casualties, and of 22 % of slight casualties.

By applying sample percentages of injury numbers and fatality reduction to the entire French accident population (1998), seat belt use could save 40 lives [25; 55] (out of a total of 8437 fatalities), and avoid 130 seriously injured occupants [95; 165] (out of 33977), and 270 slightly injured occupants [230; 310](out of 134558).

The intrinsic effect of seat belt use in trucks (*percentage of reduction of casualties in accidents concerned*) is very high and comparable to the intrinsic effect of seat belt use in cars, while the global expected effect *(percentage of reduction of casualties in all accidents)* is low.
This potential benefit can be considered valid for a use rate of 100 %. Lower use rates would lead to a lesser benefit.

The Tip-over
Even if there is no statistic relation between V_E and MAIS and between the injury causation mechanism and MAIS for tip-over accidents, projection is the most representative injury causation mechanism. There is a slight difference between clockwise (final position on right side) and counter clockwise (final position on left side) tip-over. In left tip-over, all ejections (4/4) are fatal while in right tip-over, the 8 ejections result in 2 slight, 4 severe and 2 fatal injuries.

The Airbag Effect
Accident analysis was carried out in order to evaluate the expected gain of a combined seat belt and airbag system in preventing or mitigating injuries. It is possible to distinguish, in a case by case study, the seat belt effectiveness from that of the seat belt coupled with an airbag. Among the 479 truck occupants of the CEESAR sample, 23 occupants could benefit from seat belt with an airbag, especially in truck to truck and truck to obstacle accidents. For the remaining injured occupants (160), seat belt use without an airbag is sufficient. Airbags have no effect on injury reduction in tip-over and the small car to truck sample size does not enable us to draw a valid conclusion for these crashes.

CONCLUSION

This paper provides a framework for estimating the potential benefit of seat belt use if all truck occupants wore a seatbelt.
We showed that the use of national statistics and in-depth investigation accidents could, in a case by case and with expert analysis, be used to
identify the causes of injury to truck occupants,
discuss the use of a seat belt in reducing injury severity.
propose a quantitative estimation of the potential gain.

In these kinds of truck accidents (national sample) with a 100 % seat belt and air bag use rate:
about 1/3 (-37%) of fatalities could be saved
and about 1/3 (-36%) of seriously injured occupants could be avoided.

Most of the gains are in accidents between trucks, in tip-over or in frontal impacts with fixed obstacles. Collision with cars or other types of accidents are seldom severe for truck occupants.
Potential effectiveness is mostly due to the reduction of projection or ejection of the occupant. In most intrusion cases, where intrusion is in line with the occupant, seat belt use can not prevent the occupant being impacted by an external object or by a part of the cab.
Our results differ slightly from previous research programs (Table 1). Although the results based on our sample are similar to those found in other studies, when they are weighted to take into account national statistics, the figures differ somewhat. We do not know whether the samples used in the research programs which figure in Table 1 have been weighted in the same way.

We wondered if there is a possible counter effect by use of seat belt that could reduce of its high potential benefit. This issue has been discussed for a long time by the scientific community as far as seat belts in passenger cars are concerned. It seems that the discussion is closed even though there are still reluctant drivers who keep on driving unrestrained because of the lack of comfort, pleasure or a strong belief that the belt kills more than it saves. There is only one of our accident case in which we found a potential benefit from the non-use of a seat belt. In this case, if this occupant is belted with a seat belt coupled to a pretensioner, his body will stay linked to the seat and his head will be in line with the roof intrusion (V form). In other words, there seems to be no counter effect.

The last point is the possibility of risk compensation caused by a safety feeling that seat belt could provide to the driver. This is beyond the scope of the current study.

Because the use of seat belts by truck occupants would be very effective for truck occupants even if the overall result does not bring about a large decrease in the number of road injuries (the overall road accident injury toll is due to the injuries suffered by other kinds of road users), we highly recommend the installation and a mandatory use of seat belt by truck occupants, be they drivers or passengers. This measure is a lifesaver and must not be postponed any longer.

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BIBLIOGRAPHIE

F.Alexander, W.Niewöhner, H.Bürkle,Dekra, K.Morschheuser, DaimlerChrysler, « Protection Benefit of Safety Belts in Heavy Trucks », Stuttgart, Allemagne

C.Avedal, Y.Gamstedt, « Relevance of commercial vehicle rollover accidents, Volvo Truck Corporation, Göteberg, Suède, Dekra 2000

F.Bar, « Gain à attendre de la ceinture de sécurité à bord des véhicules industriels en accidents mortels », CEESAR Centre Européen d'Etudes de Sécurité et d'Analyse des Risques, France 1995

F.Bar, "Contrôle Actif De Trajectoire Pour Véhicules Industriels En Accidents Mortels", CEESAR, France 1996

F.A.Berg, W.Niehwöhner, H. Bürkl, « Protection Benefit of Safety Belts in Heavy Trucks », DEKRA Automobil GmbH, Stuttgart, Allemagne, 2000

F.A.Berg, « Présentation on the advantage of safety belts in heavy trucks, based on analysis of real life accidents and the results of a crash test with a Mercedes Benz Actros », IRCOBI, 1999

P.Botto, « Informations techniques sur les systèmes de protection des conducteurs de véhicules industriels », CEESAR, 1996

U.Breitling, « Crash simulation and tests to improve occupant and partner safety, MAN Nutzfahrzeuge AG, Munich, Allemagne, Dekra 2000

K.H.Digges, A.C.Malliaris, H.J.Deblois, « Opportunities for casualty reduction in rollover crashes », Deblois Associates- United states- 94 S5 O 11

R.Driscoll, « Les véhicules légers en tonneaux », CEESAR 2000

Grattan, Hobbs, « Injuries of occupants of heavy goods vehicles », TRRL Transport and Road Research Laboratory, 1975

M.Groer, « Bewertung des Nutzenpotentials von passiven Schutzeinrichtungen für Nutzfahrzeuginsassen », Diploma Dissertation, Bergische Universität Gesamthochschule Wuppertal, 2000

A.Gulde, A.Bauberger, « Restraint Systems in Modern Transporters », Autoliv GmbH Werk Süd, Dachau, Germany, 2000

T.Hermitte, C.Thomas, Y.Page, T.Perron, «real world car accident reconstruction methods for crash avoidance system research», CEESAR, France FISITA 2000

K.Högström, L.Svenson, « Accidents involving Volvo trucks resulting in personal injury », Volvo report 3, 1980

M.Horii, K.Yamazaki, Y.Amemiya, « Seat belt effectiveness for heavy truck occupants during a collision », Japon, 1987

K.Langwieder, « Retrospektive Untersuchung über die innere Sicherheit von Lkw-Fahrerhaüsern », FAT-Schriftenreihe, 1988

F.Reyes, « S comme sécurité ou Scania », FranceRoutes, France, 1997

U.Stöcker, F.Nicklisch, V.Wick, « Documentation zur Sicherheit von Nutzfahrzugen », 1986

L.Svenson, « Accident investigation », Volvo, report 4, Göteborg, Suède, 1994

H.Templin, « Developping protection for heavy vehicle occupants involved in a rollover », Indiana Mills and manufacturing, inc, Heavy Vehicle Rollover TOPTEC, 2000.

T.E.Yorr, Truck, « Air bag and safety belts », SAE, USA, 1996

A.Zeller, Ralabadi, « Special Aspects of Development of Protection Systems for Commercial Vehicles », Petri AG, Berlin, Allemagne